Cortical Control of Neural Prostheses

Quarterly Report #6

Jan 1, 2001 - Mar 31, 2001

(Contract NIH-NINDS-NO1-NS-9-2321)

Submitted to the Neural Prosthesis Program
National Institute of Neurological Disorders and Stroke
National Institutes of Health

By
Andrew Schwartz, Ph.D., Principal Investigator
Gary Yamaguchi, Ph.D., Co-Principal Investigator
Stephen Helms Tillery, Ph.D.
Daryl Kipke, Ph.D.
Jiping He, Ph.D.
Jennie Si, Ph.D.
James Sweeney, Ph.D.

The Whitaker Center for Neuromechanical Control
Bioengineering Program
Arizona State University
Tempe, Arizona 85287-6006

Work Performed During the Reporting Period

Implants

We implanted recording arrays in two hemispheres during this recording period. In one hemisphere, we implanted three microwire arrays and a microdrive designed to record from deep brain structures. The microwire arrays were all in precentral cortex, areas M1 and PMd. The microdrive was implanted so that we could record first in the putamen, and then advance the electrodes into globus pallidus. Following implant, we covered the craniotomy with calcium alginate, a biocompatible polysaccharide polymer, and sealed the defect with dental acrylic. Immediately on recovery from the surgery, the animal exhibited striking clinical symptoms. The symptoms abated after about a week, and recording quality on the microwire arrays began to pick up. We were able to simultaneously record striatal units from the microdrive and cortical units on the microwire arrays during the first two weeks post-implant.

In the second hemisphere of the same animal, we implanted four microwire arrays and two Michigan probes. Again, we covered the craniotomy with calcium alginate prior to sealing it all with dental acrylic. Immediately after the surgery, the animal again exhibited clinical symptoms, which abated after several days. We recorded data and trained on the robot control (described below) for several weeks before the implants stopped producing data.

Algorithms

We have started a data-mining effort to directly compare the capabilities of various control algorithms in predicting hand trajectories from the data. We have extensive data recorded from 64 channel implants in 8 hemispheres during performance of center->out tasks. Importantly, the quality of the data varies tremendously across the set of implants. In the best cases, 30 to 40 neurons show significant linear relations between firing rate and the direction of movement. In the worst cases, fewer than 20 neurons show any relation between the direction of movement and firing rate.

In the best cases, preliminary results are that population vector produces nearly as good a prediction of hand trajectory as other methods that make fewer assumptions about the nature of the relations between firing rate and movement direction. In the worst cases, algorithms that rely only on the measured distributions of firing rates are unable to estimate from the recorded discharge the intended direction of arm movement.

We also continued work on an adaptive population vector for the direct brain control in which we use correlation measures to determine which neurons contribute most directly to the brain control, and increase the contribution of those neurons to the real-time computation of the population vector.

Finally, we have also started working on developing a maximum likelihood estimate method that we can use to quantitatively assess the hand path predictions of the algorithms.

Direct Brain Control Training

Population Vector in Virtual Reality: Two animals are currently maneuvering cursors in virtual reality by means of brain signals alone. In the previous reporting interval we briefly described an adaptive population vector algorithm which allowed us to select the most modulated neurons based on performance during the brain control task. We are now extending those results by using the outcome of the adapted population in a ballistic task. Previously, the animals were allowed an extended period of brain control in which they were able to maneuver the cursor into the target by means of error correction. In the new task, the animals are required to deliver a 'velocity impulse' to the cursor under brain control that drives it in one motion into the target. Both animals have been steadily learning to perform this task.

Robot Task In the robot task, we have had serious difficulties convincing an animal that it had control over the movement of the robot. In this period we have found a method that is working for the initial stage of this training paradigm. To use this method, we have the animals manipulate the robotic arm directly using force application at the endpoint of the robot. Their incentive for manipulating the robot is a fluid dispenser attached to the end-effector of the robot. We then look at the ensemble discharge, and identify first those neurons that have adequately high firing rate (mean rate greater than 20 spikes / second), and out of that set categorize the firing rates of the neurons in terms of a limited set of pulling directions.

Once we have an ensemble firing -> pulling direction map established, we restrain the animal's arm, and provide the animal with the opportunity to direct the motion of the robot using the map. If the animal is able to move the robot close enough, we use the robot to deliver a fluid reward.

To date, we have had two animals move quickly beyond chance performance on this task.

Auxiliary Work

We continue with our work on neurotrophic electrode arrays. We have designed a test-bed device for assessing the physiological signs of neurite growth, and have implanted the device in several rats. Preliminary evidence is that our designs do encourage neurite growth near the recording device. If the neurites actually grow into the device, we expect to obtain greatly enhanced long-term recording stability and signal-to-noise ratio. We have submitted abstracts of this work at the Biomedical Engineering Society and IEEE Engineering in Medicine and Biology Society meetings this upcoming fall.

In addition, we have obtained simultaneous recordings from the basal ganglia and motor cortical areas. We have found both signs of connectivity and evidence for simultaneous firing both between cortex and basal ganglia and within basal ganglia. We hope to continue produce adequate pilot data to seek independent funding for this project.

We have also resumed development work on a multi-site silicon fiber recording electrode. We have mechanisms for coating the fiber with metal and etching out contacts and contacts. The final stage is to coat the electrode with an insulating medium and expose the contacts through the insulator. We are presently investigating Parylene-C as a coating.

Manuscripts

We have submitted our monkey work for presentation at the 2001 Society for Neuroscience meeting, and our neurotrophic electrode work for publication at engineering meetings (BMES and EMBS).

We have also started three manuscripts on the neuroprosthetics work. One manuscript is devoted to the ability of the animals to control the cursors in the virtual reality task. A second manuscript is on our method for overcoming the stimulus-response matching problem in getting animals to use a robotic arm. The final manuscript that we are working on is a discussion of the merits of various algorithms for estimating hand velocity from the firing rate of a limited set of neurons.

Work Anticipated During the Next Reporting Period

In the next recording period, we will continue recording the from the active implants and perfuse the one animal with failed implants to see if we can determine why those implants stopped producing data.

We also anticipate continuing with an active schedule of implants. We still have the best recording success using microwire arrays, but we will continue assessing possible replacement devices, such as silicon-based Michigan probes.

We will also extend robot task to more movement directions. In the next training stage, the animals will be required to move the robotic arm in directions spanning 180 degrees. The attentional demands of the task will be larger, but we plan to keep the mapping between brain activity and robot movement fairly simple until the animal has clear control over a limited set of motions of the robotic arm.

We will also be exploring means to make a direct transition from the VR task to the robot control task. Since the animals are good at controlling cursor movement, we hope that a direct transition of control to the robotic arm might lead the animals to be more quickly able to feed themselves using the robot.

We have also built another basal ganglia microdrive, and hope for an opportunity to implant the device and do further simultaneous recordings in the motor cortex and the striatum. To date, we have found evidence for weak connectivity between cortical units and striatal units. It is not clear at this point whether striatal units will be a good source for control signals in a neuroprosthetic system, but we expect that basal ganglia will be involved in learning to use any such device.